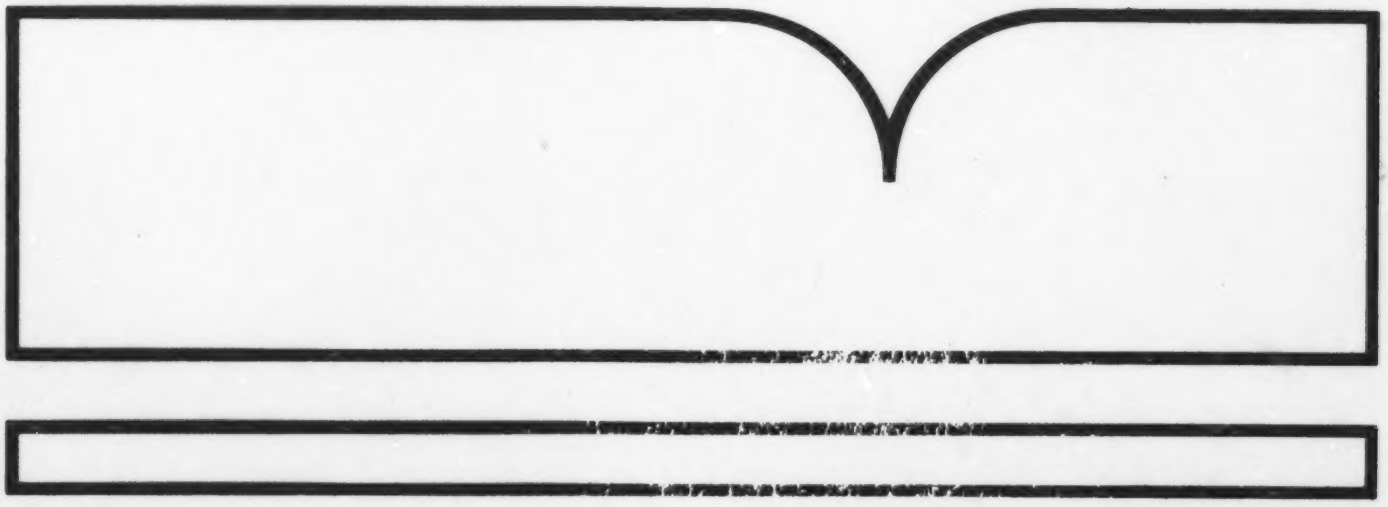
PB85-220341

Preliminary Assessment of the 10 Micrometer Particulate Sampling at Eight Locations in the United States

(U.S.) Environmental Monitoring Systems Lab.
Research Triangle Park, NC

1985



U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before complet

1. REPORT NO. EPA/600/J-85/040	2.	3. PB85-220341
4. TITLE AND SUBTITLE Preliminary Assessment of the 10 μm Particulate Sampling at Eight Locations in the United States (Journal Version)		5. REPORT DATE 1985 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Charles E. Rodes and E. Gardner Evans		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. EPA, Environmental Monitoring Systems Laboratory Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS ENVIRONMENTAL MONITORING SYSTEMS LABORATORY OFFICE OF RESEARCH AND DEVELOPMENT U.S. ENVIRONMENTAL PROTECTION AGENCY RESEARCH TRIANGLE PARK, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/08

15. SUPPLEMENTARY NOTES
Atmospheric Environment, 19(2): 293-303, February 1985

16. ABSTRACT
The first year of PM10 data from EPA's Inhalable Particulate Network are summarized and discussed. The discussion includes comparison among the various samplers and particulate size fractions. The data base is composed of measurements made on an every-sixth-day sampling schedule at 8 different locations in 1982. This preliminary review indicates that the overall ratio of PM10 to TSP is 0.485 and is a reasonably linear relationship. The relationships between PM10 and PM15 are very linear for all sites, increasing the utility of the existing PM15 data bases.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED 20 SECURITY CLASS (This page) UNCLASSIFIED	21. NO. OF PAGES 13 22. PRICE

EPA/600/J-85/040
JOURNAL ARTICLE

Atmospheric Environment Vol. 19, No. 2, pp. 293–303, 1985
Printed in Great Britain.

Pergamon Press Ltd.

PRELIMINARY ASSESSMENT OF 10 μm PARTICULATE SAMPLING AT EIGHT LOCATIONS IN THE UNITED STATES

CHARLES E. RODES and E. GARDNER EVANS
Environmental Monitoring Systems Laboratory, EPA, Research Triangle Park, NC 27711, U.S.A.

(*First received* 27 *April* 1984 *and in final form* 19 *July* 1984)

Abstract—The first year of data for 10 μm particles from the Environmental Protection Agency's Inhalable Particulate Network are summarized and discussed. The discussion includes comparison among the various samplers and particulate size fractions. The data base is composed of measurements made on an every-sixth-day sampling schedule at eight different locations in 1982. This preliminary review indicates that the overall ratio of the 10 μm fraction (PM10) to Total Suspended Particulate (TSP) is 0.485 and the relationship is reasonably linear. The relationships between PM10 and the 15 μm fraction (IP) are very linear for all sites, increasing the utility of the existing Inhalable Particulate data bases.

Key word index: PM10, TSP, fine particles, coarse particles, sampling.

INTRODUCTION

Based on a 1981 review (U.S. EPA, 1981) of the health and welfare data, EPA is considering a revision of the National Ambient Air Quality Standards for particulate matter. This review recommended that the current primary standard (*Federal Register*, 1971) for Total Suspended Particulate (TSP) be replaced by a size-specific 10 μm fraction related to penetration of particles into the respiratory system. Using the deposition model of Chan and Lippmann (1980) to establish preliminary performance specification, EPA funded the development of several sampling systems which would collect the 0–10 μm fraction, designated as PM10. Two of these inlet systems were described by McFarland and Ortiz (1982) and Wedding *et al.* (1982). Because the Wedding inlet fit existing dichotomous samplers, prototype versions were procured and deployed at 39 sites in the Inhalable Particulate Network (IPN).

The IPN was established in 1979 to collect size-specific particulate data in anticipation of a change in the primary standard. Based on the assessment by Miller *et al.* (1979), the cutpoint for the samplers in the IPN was selected at 15 μm and designated as Inhalable Particulate (IP). Inlets with 15 m cutpoints were developed and samplers deployed from 1979 to 1981 at over 100 sites in the U.S.A. Using hi-vol and dichotomous samplers and size-selective inlet (SSI) hi-vols at some sites, data on the TSP, FINE (< 2.5 μm), COARSE (2.5–15 μm) and PM15 fractions were collected. The data for the period April 1979–June 1980 were summarized and reported by Suggs *et al.* (1981). A more exhaustive evaluation of these IPN data was also prepared by Watson *et al.* (1981). Data for the IP fraction is designated as PM15 in the present report.

A proposed conversion to a PM10 standard initiated efforts toward the development of 10 μm size-specific inlets and their subsequent deployment in the IPN. The initial emphasis was the conversion of the dichotomous sampler inlets at 39 sites from PM15 to PM10. These 'key' sites were selected by EPA's Office of Air Quality Planning and Standards to represent a cross-section of U.S. cities with an emphasis on non-compliance problem areas. In order to permit intercomparisons between the old and new data, a dichotomous sampler with a PM10 inlet was collocated with the PM15 version at the first few sites established. To provide an additional comparison 15 μm cutpoint SSI hi-vols (designated SSI15) were also operated. Eight sites were established by March 1982. This report summarizes the 1982 data from these first eight sites which are listed in Table 1. Intercomparisons of the various particulate fraction are made with an emphasis on the PM10 measurements. The interpretations of the data must be considered preliminary in that the every-sixth-day sampling schedule for the 9–12 months of 1982 operation has produced only a limited data base.

SAMPLE COLLECTION

The samplers used at each of the eight PM10 sites include a standard TSP high volume sampler a 15 μm Size Selective Inlet hi-vol, a 15 μm dichotomous sampler, and a 10 μm dichotomous sampler. The sampling effectiveness of the TSP hi-vol is very wind speed dependent as shown by McFarland and Rodes (1979). Sampling effectiveness is defined as the fractional concentration of particles reaching the filter as compared to that outside the inlet. For most sampling systems the effectiveness below about 2 μm is 100%, and above this point decreases as the particle size increases. The cutpoint or D_{50} (size at 50% effective-

Table 1. IPN Sites with TSP, SSI15, PM15 and PM10 samplers

City	Address	EPA Site No.
Birmingham, AL	3009 28th St.	01-0380-023
Buffalo, NY	1515 S. Park Ave.	33-0660-010
Houston, TX	1224 Mae Dr.	45-2560-034
Philadelphia, PA	500 S. Broad St.	39-7140-003
Phoenix, AZ	1845 Roosevelt St.	03-0600-002
Pittsburgh, PA	600 Anderson St.	39-6620-001
Rubidoux (Los Angeles), CA	58888 Mission Blvd.	05-6535-001
Steubenville, OH	814 Adams St.	36-6420-012

ness) for the TSP hi-vol changes from about 50 μm at 2 km h^{-1} winds to 22 μm in 24 km h^{-1}.

Size-selective inlet PM-15 hi-vols utilize all of the components of the TSP hi-vol except the gable roof inlet. In its place an inlet designed by McFarland and Ortiz (1979) is used which provides a D_{50} of 15 μm at a sampling flowrate of 1.13 m^3 min^{-1} (40CFM). This inlet exhibits a moderate shift in D_{50} from 16.2 μm at 2 km h^{-1} to 12.8 μm at 24 km h^{-1}. This shift is not insignificant but is much less pronounced than that of the TSP version.

The dichotomous sampler operates at 16.7 ℓ min^{-1} and divides the fraction defined by the inlet D_{50} into two smaller fractions above and below 2.5 μm. These subfractions are designated as the COARSE and FINE fractions, respectively. The upper size limit of the COARSE fraction is that of the 10 or 15 μm inlet.

The PM15 dichotomous sampler inlet is a commercial version sold by Sierra and evaluated by Wedding *et al.* (1980). This inlet is only slightly less wind speed dependent than the TSP hi-vol with a D_{50} shift from 22 μm at 5 km h^{-1} to 10 μm at 40 km h^{-1}. This inlet represents the technology available early in EPA's size-specific inlet development program and is basically a vertical elutriator. The D_{50} of the inlet is 15 μm at 15 km h^{-1}, which is near the annual mean windspeed for the continental U.S.A.

The PM10 inlet used on the dichotomous samplers in the IPN has the sampling effectiveness characteristics of Wedding *et al.* (1982). The recent advances in particle separation technology are inherent in this PM10 inlet as demonstrated by the D_{50} which is 10 μm ± 1 for all three windspeeds tested. The PM10 inlet appears physically similar to the PM15 version but is much more complex internally and incorporates an added cyclone separator.

The filter material used on the hi-vols and SSI's were standard 8 × 10 inch. glass fiber filters procured by EPA for use by the State and Local Air Monitoring Sites in 1982. This batch of filters was manufactured by Whatman and evaluated by Appel *et al.* (1982) and found to produce sulfate artifact mass averaging approximately 8 μg m^{-3}. This additional mass can cause significant errors at low total concentrations, especially in comparisons with other samplers. The dichotomous samplers use 37 mm Teflon filters, which are considered to have little sulfate artifact. Because of these differences EPA decided not to utilize the SSI data as interchangeable with the PM15 data from dichotomous samplers.

The sampling sites are operated by local agency personnel following standard operating and flowcheck procedures. As a quality control check selected sites in the IPN include collected duplicate samplers to permit estimation of network precision. The Philadelphia site is the only location summarized in this report which includes duplicate pairs of PM10 and PM15 dichotomous samplers. The collected samples are mailed to the central EPA laboratory at Research Triangle Park, N.C. for gravimetric analysis. Using manual and computer-assisted validation procedures, all results are screened to identify potential errors. Validated results are stored and available for EPA and public access.

DATA BASE

The total number of possible sampling days in 1982 following the every-sixth-day schedule is 61. As shown in Table 2 the actual number of sampling days at some of the sites was substantially less than this number primarily because the PM10 sampler deployments were delayed. The PM10 dichotomous samplers in Birmingham and Houston were not operational until 24 March 1982. The TSP hi-vol was discontinued in Pittsburg early in the year and no statistics can be computed which include this fraction. In addition, the SSI15 and PM15 dichotomous sampler at this site were only operated for part of the year. Sampling at the Philadelphia site did not begin for any sampler until 6 March 1982. The TSP hi-vol in Steubenville was not operational until 10 June 1982 and only intermittently during the rest of the year. These shortcomings in the data base must be considered in examination of the averages and ratios. The data bases are, however, adequate to provide an indication of the levels and relationships to be expected as more data are collected.

The eight sites reported here are not necessarily typical urban locations, and the site location within the metropolitan area must also be considered. Several were selected because they represent industrialized locations which substantially exceed the existing TSP annual average of 75 μg m^{-3}. This latter group includes the Birmingham, Houston and Steubenville locations. The other sites were selected to be representative of areas with long range transport, large population exposures, or specific source category influences.

CONCENTRATION DATA

As noted in Table 2 data are available from four different samplers at all sites but Pittsburgh. The Philadelphia site also includes collocated dichotomous PM15 and PM10 samplers. Since each dichotomous sampler provides COARSE, FINE and TOTAL information, eight measurement categories are available at most sites. These are listed in Table 3. Although the PM15 and SSI15 fractions are nominally the same, the differences in effectiveness curves and the filter artifact potentials described earlier can produce biases. The F10 and F15 fractions collected by both 10 and 15 μm dichotomous samplers should theoretically be identical, since the PM10 and PM15 inlets affect only the COARSE fractions.

The arithmetic mean concentrations and standard deviations for each site are given in Table 4. These results are calculated using all available data for each fraction without regard to the availability of other fractions. The arithmetic mean is calculated instead of the geometric mean as recommended by the latest EPA review of the particulate standard. As noted earlier five of these sites exceeded the existing TSP standard, with Rubidoux having the highest mean of 128.5 $\mu g\,m^{-3}$.

As shown by the percentages in Table 2 and the number (n) of valid sampling days in Table 4 most of the averages are not representative of a calendar year. This makes observations of seasonal effects almost impossible as demonstrated by the plots of TSP and PM10 by sampling day for the Birmingham and Rubidoux sites in Figs 1 and 2, respectively. The Birmingham data as shown in Fig. 1 had two high level excursions in March and May which appear not to be related to either the season or the meteorology. These two peaks gave atypical TSP and PM10 standard deviations as shown in Table 4. A comparison of measurements (e.g. SSI15 > TSP, SSI15 ≫ PM15) in Steubenville suggests sampler problems such as leaks or flow calibration errors. Since this has not yet been verified the Steubenville data should be considered questionable.

The 15 μm measurements (SSI15 and PM15) as expected fall between the TSP and PM10 concentrations. A comparison of PM15 and SSI15 using only paired measurements at each site is given in Table 5. Excluding Steubenville the differences between the means for 1982 ranged from 8.7 $\mu g\,m^{-3}$ in Rubidoux to 27.1 $\mu g\,m^{-3}$ in Phoenix.

Reporting the simple ratio of SSI15/PM15 can give a misleading statistic as shown in Table 5 and illustrated by the Philadelphia data in Fig. 3. Although Philadelphia SSI15 concentrations on the average are 44% greater than those for PM15, the regression suggests that the problem may be a combination of an intercept that is different from zero and a slope that is not unity. These differences have also been noted by Watson *et al.* (1983) and Nelson and Wijnberg (1981), who both reviewed earlier IPN data. The combination of differences in inlet effectiveness curves and artifact potential on the filter probably accounts for most of the biases.

The average PM10 concentrations for the eight sites ranged from 34.8 $\mu g\,m^{-3}$ in Buffalo to 74.5 $\mu g\,m^{-3}$ in Rubidoux. These can be compared to the respective collocated TSP measurements of 70.3 and 126.7 $\mu g\,m^{-3}$ at the same sites. Three of the eight sites considered exceeded an annual average PM10 level of 40 $\mu g\,m^{-3}$, but only two exceeded 50 $\mu g\,m^{-3}$. An analysis of the frequency of occurrence of the daily PM10 concentrations for each site is given in Table 6. Only three 24-h PM10 measurements during the year exceeded 150 $\mu g\,m^{-3}$ at any of the sites. Two of these

Table 2. Percentage data capture by site

Site	TSP	SSI15	PM15	PM10
Birmingham	84	85	87	59
Buffalo	72	80	66	61
Houston*	62	56	20	25
Philadelphia	74	74	64(56)†	57(44)†
Phoenix	93	84	90	80
Pittsburgh	3‡	16‡	61	72
Rubidoux	75	84	80	77
Steubenville	18	44	51	48

*Site not put on-line until 24 March 1982.

†Numbers in parenthesis are for collocated duplicate sampler.

‡Sampling discontinued early in the year. Data not included in subsequent computations.

Table 3. IPN sample measurement categories

Category	Sampler	Size range (μm)	Category designation
Total suspended particulate	Hi-Vol	0–30*	TSP
15 μm TOTAL	Size-selective inlet Hi-Vol	0–15	SSI15
15 μm TOTAL	Dichotomous	0–15	PM15
15 μm FINE	Dichotomous	0–2.5	F15
15 μm COARSE	Dichotomous	2.5–15	C15
10 μm TOTAL	Dichotomous	0–10	PM10
10 μm FINE	Dichotomous	0–2.5	F10
10 μm COARSE	Dichotomous	2.5–10	C10

*Approximate.

Table 4. Arithmetic means and standard deviations of particulate fractions for 1982

Site		TSP	SSI 15	PM 15	F 15	C 15	PM 10	F 10	C 10
Birmingham	*n*	54	55	56	56	56	39	39	39
	x	107.6	76.0	61.0	29.0	32.4	50.1	28.6	21.4
	s	70.0	42.9	34.9	13.6	25.4	33.3	15.5	19.5
Buffalo	*n*	44	49	40	40	40	37	37	37
	x	70.3	54.3	42.1	20.6	21.5	34.8	19.9	14.9
	s	32.0	23.0	19.9	10.3	13.4	17.6	9.4	11.0
Houston	*n*	38	34	12	12	12	15	15	15
	x	101.8	65.1	47.4	20.7	26.7	37.6	17.0	20.0
	s	38.1	20.4	18.0	18.4	10.3	10.9	6.6	7.5
Philadelphia	*n*	45	45	39	39	39	35	35	35
	x	67.9	53.6	39.5	24.2	15.3	35.2	24.5	10.8
	s	21.0	18.2	13.4	10.2	6.8	12.5	10.4	4.2
Phoenix	*n*	52	51	54	54	54	49	49	49
	x	103.3	79.2	53.7	17.7	38.9	39.0	15.2	23.3
	s	34.0	29.4	20.6	12.0	14.2	17.9	9.8	11.1
Pittsburgh	*n*		10	37	37	37	44	44	44
	x	—	61.3	39.8	22.7	17.2	36.9	24.4	12.5
	s	—	22.5	19.2	14.9	7.9	19.3	15.3	7.3
Rubidoux	*n*	47	51	49	49	49	45	45	45
	x	126.7	100.6	93.2	44.9	48.2	74.5	40.6	33.9
	s	57.8	49.7	44.7	28.5	26.3	35.1	26.5	16.5
Steubenville	*n*	11	27	31	31	31	29	29	29
	x	89.7	93.0	47.5	28.4	19.2	41.0	25.5	15.3
	s	39.5	34.4	21.6	14.2	10.1	22.4	12.6	11.1

Notes: (2) See Table 3 for column heading description.
n, valid sampling; *x*, arithmetic mean; *s*, arithmetic standard deviation.

(172.2 and 170.8 $\mu g\,m^{-3}$) occurred on consecutive days in May at the Birmingham site. The highest single day (199.1 $\mu g\,m^{-3}$) occurred on 22 February in Rubidoux. The TSP levels during the two high PM10 days in Birmingham were 311.5 and 368.5 $\mu g\,m^{-3}$ and well in excess of the 260 $\mu g\,m^{-3}$ single day standard. A TSP value is not available for the highest PM10 day in Rubidoux.

Duplicate PM15 and PM10 dichotomous samplers were operated at the Philadelphia site to provide an indication of precision for these measurements under network operating conditions. In order to make valid comparisons only paired measurements are considered and percentage differences are determined for each sampling day. The average percentage differences for 1982 are given in Table 7 for each size fraction along

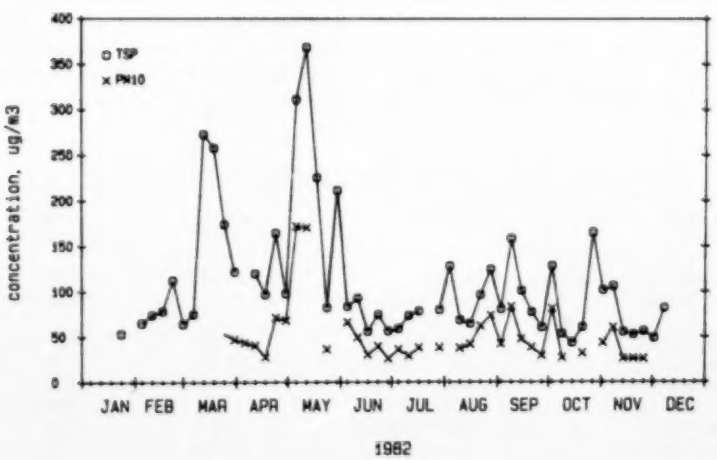


Fig. 1. Birmingham 1982 IPN Data.

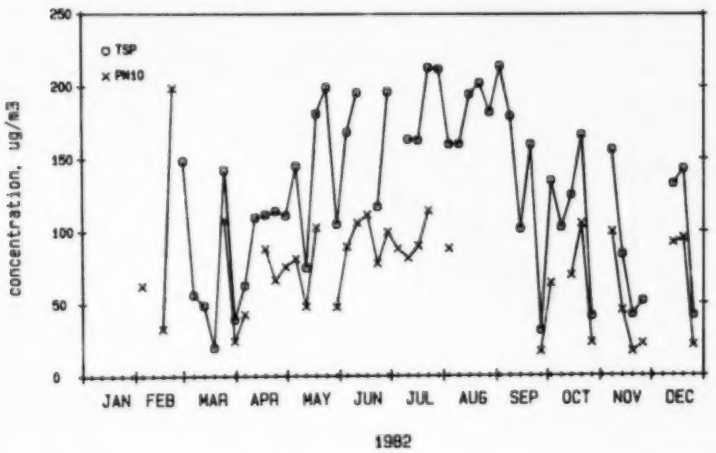


Fig. 2. Rubidoux 1982 IPN Data.

Table 5. Comparison of PM15 and SSI15 using collocated measurements

Site	n	Av. diff. $\mu g\,m^{-3}$	Ratio (SSI15/PM15)	Slope*	Intercept ($\mu g\,m^{-3}$)*
Birmingham	52	14.2	1.271	1.167	3.86
Buffalo	32	16.0	1.454	1.248	6.04
Houston	9	15.8†	—	—	—
Phoenix	46	27.1	1.558	1.276	12.78§
Philadelphia	38	16.4	1.440	1.145	10.58§
Pittsburgh	10	23.9†	—	—	—
Rubidoux	46	8.7	1.174	0.986	9.93
Steubenville	22	44.6‡	—	—	—
Overall	255	19.8	1.455	1.03	17.79§

Notes: *Linear regression of PM15 (x) vs SSI15 (y).
†$n \leq 10$.
‡Probable error in measurements.
§Significantly different from zero at 0.95 level.

Table 6. Distribution of 24-h PM10 concentrations for 1982

Site	Number of days exceeding a given PM10 concentration in $\mu g\,m^{-3}$										No. of days exceeding TSP of $260\,\mu g\,m^{-3}$
	< 50	≧ 50	≧ 75	≧ 100	≧ 125	≧ 150	≧ 175	≧ 200	≧ 225	≧ 250	
Birmingham	24	12	6	2	2	2	0	0	0	0	3
Buffalo	30	7	1	0	0	0	0	0	0	0	0
Houston	13	2	0	0	0	0	0	0	0	0	0
Philadelphia	30	5	0	0	0	0	0	0	0	0	0
Phoenix	39	10	3	0	0	0	0	0	0	0	0
Pittsburgh	37	7	1	1	1	0	0	0	0	0	N/A
Rubidoux	9	26	22	9	1	1	1	0	0	0	0
Steubenville	21	8	3	0	0	0	0	0	0	0	0

Note: See Table 4 (or add columns 1 and 2) for the total number of PM10 days at each site.

with the coefficient of variation of the average differences. Even the largest bias of -4.2% for the duplicate PM15 fraction is excellent, considering the allowable flow calibration error limits of $\pm 10\%$. Since the inlet theoretically has almost no effect on the FINE fraction, an indication of the precision of dichotomous measurements can also be obtained by comparing F15 and F10. Table 8 gives the average percent differences between the measurements and the coefficient of variation of these differences.

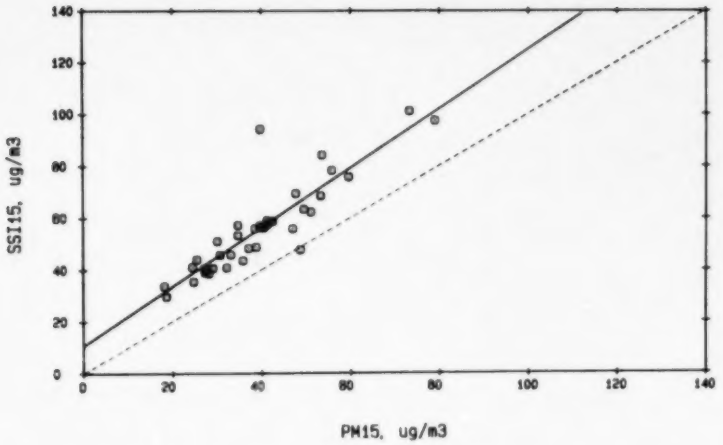


Fig. 3. Philadelphia 1982 IPN Data.

Table 7. Precision of PM15 and PM10 dichotomous sampler measurements for 1982 based on Philadelphia data

Fraction	% Difference	Coefficient of variation (%)*
PM15	−4.2	3.5
F15	−3.1	4.7
C15	−5.1	6.4
PM10	−0.9	4.3
F10	−1.5	2.2
C10	2.5	9.5

*Defined here as the standard deviation of % differences divided by $\sqrt{2}$.

Table 8. Comparison of dichotomous FINE measurements by site

Site	% difference*	Coefficient of variation (%)†
Birmingham	−1.6	8.9
Buffalo	−0.4	3.6
Houston	+1.8	10.4
Philadelphia	+1.8	10.0
Phoenix	−3.3	14.2
Pittsburgh	−4.4	7.0
Rubidoux	−5.7	6.0
Steubenville	−10.5	14.6

*Based on 1982 F10 vs F15 measurements.

†Defined here as std. dev. of % differences divided by $\sqrt{2}$.

Even though duplicate TSP and SSI15 measurements were not available for 1982, data were examined in 1980 and 1981 by Hinton *et al.* (1983). The TSP coefficient of variation was 4.7 and 6.0% in Birmingham and Philadelphia. Similarly the SSI coefficients of variation were 7.8 and 6.5%.

In general the precisions of the measurements in the IPN study are excellent considering the scope and complexity of the effort. Conclusions on the network precision cannot be made based on one site due to the many errors that can be introduced by different operators.

COMPARISONS BETWEEN MEASUREMENTS

The intercomparisons of the various particulate fractions is important in utilization of historical TSP and PM15 data and in the setting of the proposed PM10 standard. These data analyses can also quantify differences caused by flaws in the sampling systems. One of the simplest means of comparing data is to calculate the ratios between the daily measurements. A more complex approach in the fitting of a selected regression model to relate the data. To be of maximum value the physical basis for the regression should be known and mathematically consistent with the measurements. Regressions should be used cautiously since one or both samplers may have unidentified biases or variance components (e.g. a difference in filter artifact potential) which can affect the validity of the way the regression is used.

Comparison of particulate fractions of different sizes poses a problem in that the mathematical relationships between the collected fractions are complex and not readily available. The mass distribution by particle size data of Whitby *et al.* (1975) illustrates the bimodal nature of the particles suspended in the ambient air. Samplers impose their collection effectiveness relationships on these distributions, providing an integrated sample collected on the filter.

A mathematical analysis by Watson *et al.* (1981) concluded that if the shape of the size distribution at a given site remains constant, the ratio between particulate size fractions will be linear. It was noted that even though distribution shapes are not strictly constant, they tend to be similar from day to day if the

Table 9. Comparison of PM10 and TSP

Site	n	Mean TSP ($\mu g\,m^{-3}$)	Mean PM10 ($\mu g\,m^{-3}$)	Mean difference $\mu g\,m^{-3}$	Mean ratio	Std. dev. ratio	Linear regression		Correlation coefficient
							Slope	Intercept	
Birmingham	37	102.0	50.9	51.1	0.506	0.105	0.478	2.06	0.942
Buffalo	25	75.5	37.1	38.5	0.478	0.101	0.464	2.02	0.914
Houston	11	—	—	—	—	—	—	—	—
Philadelphia	31	71.0	35.4	35.6	0.496	0.091	0.548	−3.40	0.888
Phoenix	43	99.2	38.9	60.2	0.381	0.082	0.488	−9.41*	0.887
Pittsburgh	†	—	—	—	—	—	—	—	—
Rubidoux	39	130.4	71.7	58.8	0.577	0.093	0.561	2.45	0.909
Steubenville	7	—	—	—	—	—	—	—	—
Overall	175	—	—	50.3	0.485	0.093	0.502	−1.62	0.914

* Statistically different from zero at 0.95 level.
† TSP data unavailable.

local sources and meteorology are relatively consistent. To examine this hypothesis scatter plots of PM10 vs TSP were prepared for the sites in Table 1 having at least 20 data pairs. The statistics as shown in Table 9 indicate that even between sites the regression slopes are reasonably consistent, varying from 0.464 to 0.561. There are differences between these slopes and the simple average ratios of PM10/TSP, especially for the Phoenix data which showed the only intercept that was statistically different from zero. It is speculated that excessive dry particle bounce in the hi-vol sampler or settling of particles on the hi-vol filter when it is not operational as described by Lizarrago-Rocha (1976) may add significantly to the TSP mass in Phoenix, resulting in smaller PM10/TSP ratios. In addition artifact differences between the filter substrates should also account for a significant X-intercept for all samplers, but is probably masked by other differences. A composite of all available 1982 data for the five sites with adequate TSP data is plotted in Fig. 4.

If the relationship of such widely different size fraction as TSP and PM10 are reasonably linear, it could be expected that PM10 should have an excellent linear correlation with PM15. This is the case as illustrated by the composite data for all sites shown by the plot in Fig. 5. The statistics for all sites are given in Table 10 and reflect correlation coefficients of 0.95 or greater. The ratios are reasonably consistent from site to site with a mean of 0.85, but show moderate extremes in the Phoenix and Pittsburg data. The statistically significant non-zero intercept in Birmingham is also unexpected. Examination of the relative bias data in Table 8 between F10 and F15 does not explain the difference, indicating a problem in the coarse measurements. Watson *et al.* (1983) estimated the ratio of PM10 to PM15 to range from 0.82 to 0.87 using the 'expected mass collected' approach.

The relationship of PM15 to TSP could be expected to be more linear than PM10 to TSP because the size fractions are closer. The summary statistics in Table 11 as compared to Table 9 shows that the correlation coefficients are larger in each case for PM15 to TSP.

The sample collection schedule of every-sixth-day combined with low data capture does not permit an extensive assessment of day-to-day variability of the ratios of measurements. Plotting the available ratios

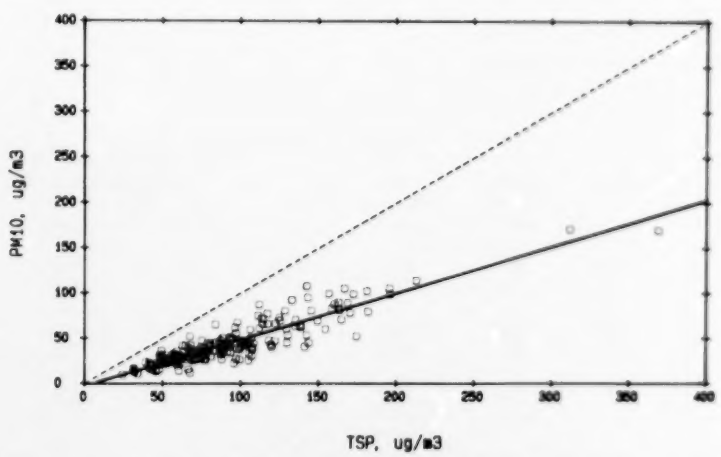


Fig. 4. Composite of 1982 IPN Data for PM10 vs TSP from Birmingham, Buffalo, Philadelphia, Phoenix and Rubidoux.

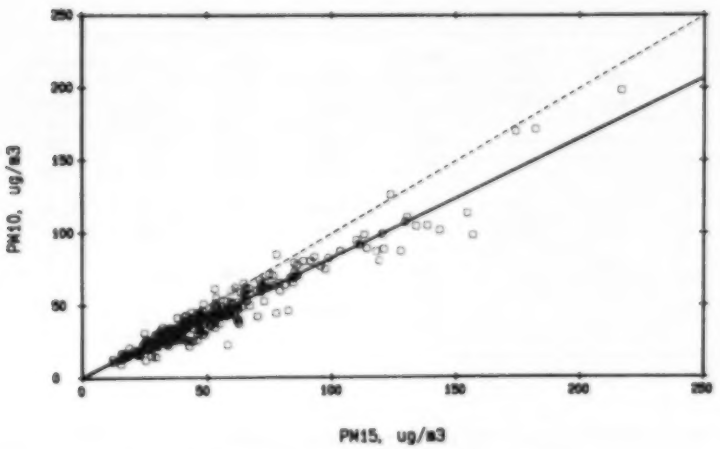


Fig. 5. Composite of all 1982 IPN Data for PM10 vs PM15.

for PM10/TSP and PM15/TSP by sampling day does provide an indication of the day-to-day variability that could be expected as illustrated in Fig. 6 for Birmingham. The standard deviation of the daily PM10/TSP ratios by site are similar and given in Table 9, varying from 0.082 to 0.105. No clear seasonal patterns are apparent for any of the sites for these ratios.

The relationship of C10/F10 for each site can provide information as to the influence of localized particulate sources, since the particles above and below 2.5 μm tend to originate from different sources. For

Table 10. Comparison of PM10 and PM15

Site	n	Mean PM15 $\mu g\,m^{-3}$	Mean PM10 $\mu g\,m^{-3}$	Mean difference $\mu g\,m^{-3}$	Mean ratio	Linear regression		Correlation coefficient
						Slope	Intercept	
Birmingham	37	59.7	50.9	8.8	0.834	0.963	−6.71*	0.979
Buffalo	25	41.9	37.1	4.8	0.870	0.904	−1.23	0.979
Houston	5	—	—	—	—	—	—	—
Philadelphia	31	40.2	35.4	4.7	0.891	0.848	1.51	0.951
Phoenix	43	52.1	39.0	13.1	0.748	0.826	−3.99	0.958
Pittsburgh	33	41.4	40.3	1.1	0.961	1.041	−2.81	0.984
Rubidoux	39	92.0	71.7	20.3	0.805	0.726	4.86	0.97
Steubenville	24	49.2	42.0	7.3	0.852	0.907	−2.69	0.927
Overall	232	—	—	9.3	0.845	0.794	1.06	0.970

* Statistically different from zero at 0.95 level.

Table 11. Comparison of PM15 and TSP

Site	n	Mean TSP $\mu g\,m^{-3}$	Mean PM15 $\mu g\,m^{-3}$	Mean difference $\mu g\,m^{-3}$	Mean ratio	Linear regression		Correlation coefficient
						Slope	Intercept	
Birmingham	37	109.8	59.7	47.4	0.595	0.483	10.5*	0.935
Buffalo	25	74.1	41.9	32.9	0.556	0.500	4.2	0.913
Houston	9	—	—	—	—	—	—	—
Philadelphia	31	70.4	40.2	30.8	0.561	0.638	−5.2	0.929
Phoenix	43	103.6	52.1	49.3	0.516	0.600	−7.4	0.935
Pittsburgh	†	—	—	—	—	—	—	—
Rubidoux	39	118.9	92.0	19.6	0.735	0.671	+4.5	0.928
Steubenville	8	—	—	—	—	—	—	—
Overall	181	—	—	36.7	0.595	0.614	−1.66	0.915

* Statistically different from zero at 0.95 level.
† TSP data unavailable.

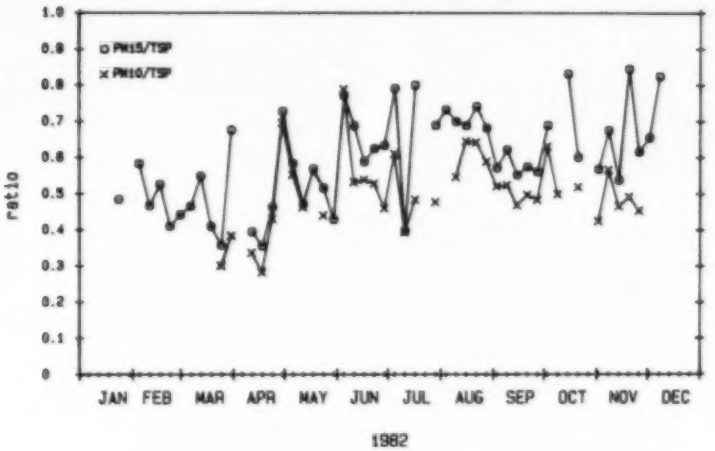


Fig. 6. Birmingham 1982 IPN Data.

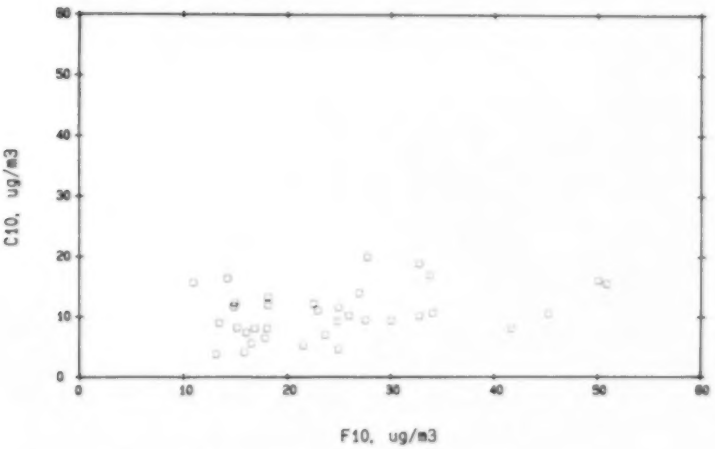


Fig. 7. Philadelphia 1982 IPN Data PM10 COARSE vs FINE.

most locations there is no expected correlation between the fractions unless a single local source is contributing particles to both fractions. The scatter plot for F10 vs C10 for the Philadelphia site in Fig. 7 is typical of other locations and shows no discernable pattern. Table 12 summarizes the mean ratios of C10/F10 by site and shows large coefficients of variations, which typically range from 40 to 55 %. As illustrated by the scatter plot in Fig. 8 for Phoenix the C10/F10 ratio appears to be unrelated to the total PM10 concentration for any of the sites. The day-to-day variations of this ratio, however, can be informa-

Table 12. Ratio of C10/F10 by site

		Ratio of C10/F10		
Site	*n*	Mean	Std. dev.	Coef. of variation (%)
Birmingham	41	0.744	0.371	49.3
Buffalo	37	0.760	0.408	53.7
Houston	15	1.336	0.545	40.8
Philadelphia	35	0.494	0.268	54.3
Phoenix	49	1.746	0.749	42.9
Pittsburg	44	0.559	0.295	52.8
Rubidoux	47	1.066	0.805	75.6
Steubenville	29	0.598	0.249	41.6

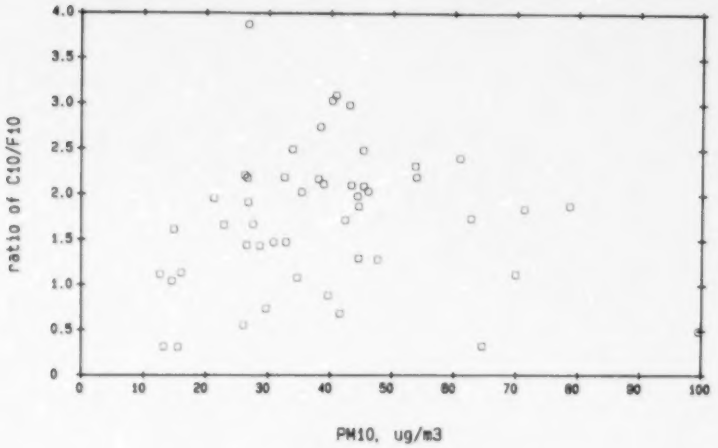


Fig. 8. Phoenix 1982 IPN Data PM10 vs C10/F10 ratio.

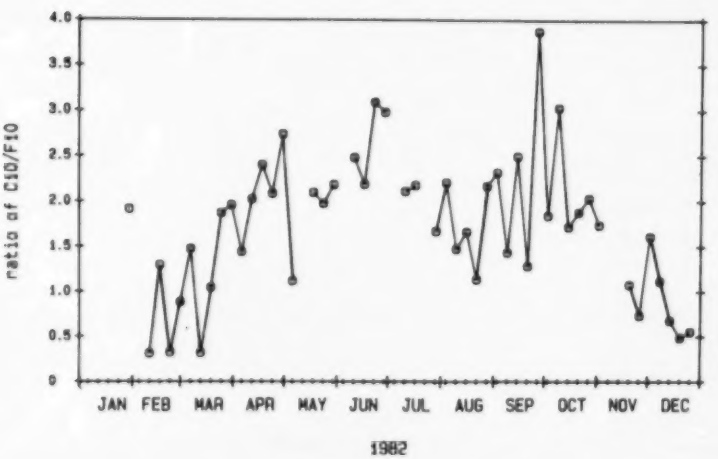


Fig. 9. Phoenix 1932 IPN Data.

tive as shown in Fig. 9 for Phoenix. This plot shows a significant seasonal trend in the ratio with the COARSE fraction dominating during the summer months. This seasonal pattern is interesting in that neither the TSP nor PM10 concentrations appear to show seasonal variations at this site.

DISCUSSION

As discussed by Thrall and Burton (1983) when considering all sites in the Inhalable Particulate Network, it is very difficult to describe the representativeness of network data. The present report considers only 1982 data from eight sites, which is a small sample from which to draw conclusions. The primary purpose of this report is to provide a preliminary analysis of the PM10 data base being established in the IP Network and even at this stage some significant results are apparent. Probably of greatest importance is the apparent predictability of the PM10 data using the PM15 measurements from a given site. The network has collected a substantial amount of PM15 data during the past several years which can be utilized as surrogate data to expand our present understanding of PM10. Strong linear relationships exist between these fractions at all of the sites examined. The mean difference between the fractions of 15% was predicted by EPA and other researchers using the mathematical 'mass collected' technique described by Wedding and Carney (1983).

The relationships between the ratios of both PM10 and PM15 to TSP are more consistent (have fewer outliers) in the present analysis than was described by reviews of earlier 1979–1981 IPN data. This can be attributed primarily to an intensified effort during the past year to identify defective samples and correct

transcription and keypunch errors during the validation process. The site operators as reflected by the collocated sampling and flow calibration audit results have done an excellent job in helping to maintain the data quality. The biggest single concern, given a 6th day sampling schedule, is the impact of low data capture percentages on the usefulness of the data. It is very difficult to feel confident with pattern or trend assessments when the data capture drops below 50%. Watson *et al.* (1981) noted that average annual concentrations (and ratios) calculated from the earlier IPN data changed significantly when the number of observations dropped below 15. The present analysis also supports this conclusion.

The PM15 to TSP ratios for 1982 are only available from five of the eight sites considered in this analysis. The average of the PM15/TSP ratios for these five sites of 0.59 is consistent with the 0.61 and 0.55 ratios reported by Thrall and Burton (1983) for the 1980 and 1981 IPN averages, respectively. The suggestion by these researchers as well as Watson *et al.* (1981) that the ratio of PM15/TSP (or PM10/TSP) varies with TSP concentration seems unsupported by the current analysis. Perhaps due to the limited number of sites and available samples per site there appears to be no difference in levels or degree of variability in the ratios at larger TSP concentrations. The mean overall ratio of 0.485 for PM10 to TSP was expected, even though the degree of linearity between measurements was not. The predicted ratio from the slope of the linear regression (0.502) was similar to the overall ratio with a 95% confidence interval about the slope of ± 0.033. The coefficient of variation (s/x) of the overall ratio was $\pm 19.2\%$. It could be expected that the range of ratios would change as other sites, especially less urban locations, are added to the data base.

The annual average PM10 concentrations ranged from 34.8 to 74.5 $\mu g\,m^{-3}$ at the eight sites with only 12 daily measurements for the entire year exceeding 100 $\mu g\,m^{-3}$. The maximum reported PM10 value at any site was 199.1 $\mu g\,m^{-3}$ at Rubidoux. It should be stressed again that the 8 sites reported are not representative of the U.S. The additional PM10 sites including non-urban locations added to the IP Network in late 1982 and early 1983 will provide a broader data base for more detailed evaluations.

Acknowledgements—The coordinated effort of the EPA personnel supporting the IPN and the assistance of the agencies who operate the IPN samplers are greatly appreciated.

REFERENCES

Appel B. K., Tokiwa Y., Haik M. and Kothny E. L. (1980) Artifact particulate sulfate and nitrate formation on filter media. *Atmospheric Environment* **18,** 409–416.

Chan T. L. and Lippmann M. L. (1980) Experimental measurements and empirical modelling of the regional deposition of inhaled particles in humans. *Am. ind. hyg. Ass. J.* **41,** 399–408.

Federal Register (1971) National primary and secondary ambient air standards, Appendix B. Reference method for the determination of suspended particulate in the atmosphere. *Fed. Reg.* **36** (84), 8186–8201.

Hinton D. O., Suggs J. C. and Sune J. M. (1983) Summary of PM-15 data differences available from collocated field samplers from June 1979 through June 1982. Internal EPA report 7/28/83, Research Triangle Park, N.C., 27711.

Lizarrago-Rocha J. A. (1976) The effect of exposure of filters during non-operating periods in the high volume sampling method. M.S. thesis, University of North Carolina, Chapel Hill, N.C.

McFarland A. R. and Ortiz C. A. (1982) A 10-μm cutpoint ambient aerosol sampling inlet. *Atmospheric Environment* **16,** 2959–2965.

McFarland A. R. and Rodes C. E. (1979) Characteristics of aerosol samplers used in ambient air monitoring. Presented at 86th National Meeting, AIChE, Houston, TX.

Miller F. J., Gardner D. E., Graham J. A., Lee R. E., Wilson W. E. and Bachmann J. D. (1979) Size considerations for establishing a standard for inhalable particles. *J. Air Pollut. Control Ass.* **29,** 610–615.

Nelson C. A. and Wijnberg L. (1981) Determination of an empirically derived IP/TSP relationship. Report prepared for EPA by PEDCo Environmental, Inc. under Contract 68-02-3173, Research Triangle Park, N.C.

Suggs J. C., Rodes C. E., Evans E. G. and Baumgardner R. E. (1981) Inhalable particulate network annual report: operations and data summary (mass concentrations only) April 1979–June 1980, EPA Report 600/4-81-037, (available from National Technical Information Service, Springfield, VA, 22161).

Thrall A. D. and Burton C. S. (1983) Characterizing ratios of particulate concentrations: a preliminary step in assessing likely attainment status under a PM10 national ambient air quality standard. Final report from EPA Contract No. 68-02-3570, Systems Application, Inc., San Rafael, CA.

U.S. Environmental Protection Agency (1981) Review of the national ambient air quality standards for particulate matter: revised draft staff paper, prepared by Strategies and Air Standards Division, Office of Air Quality Planning and Standards, Research Triangle Park, N.C. 27711.

Watson J. G., Chow J. C. and Shah J. J. (1981) Analysis of measurements from the inhalable particulate matter sampling network, final report of EPA Contract 68-02-2542, Task 6, (available as ERT Document A 394-140), Environmental Research and Technology, Inc., Concord, MS, 07142.

Watson J. G., Chow J. C., Shah J. J. and Pace T. G. (1983) The effect of sampling inlets on the PM10 and PM15 to TSP Ratios. *J. Air Pollut. Control Ass.* **33,** 114–119.

Wedding J. B. and Carney T. C. (1983) A quantitative technique for determining the impact of non-ideal ambient sampler inlets on the collected mass. *Atmospheric Environment* **17,** 873–882.

Wedding J. B., Weigand A. W. and Carney T. C. (1982) A 10-μm cutpoint inlet for the dichotomous sampler. *Envir. Sci. Technol.* **16,** 602–606.

Wedding J. B., Weigand M., John W. and Wall S. (1980) Sampling effectiveness of the inlet to the dichotomous sampler. *Envir. Sci. Technol.* **14,** 1367–1370.

Whitby K. T., Glask W. E., Marple V. A., Sverdrup G. M., Sem G. J., Willeke K., Liu B. Y. H. and Pui D. Y. H. (1975) Characterization of California aerosols—I. Size distributions of freeway aerosols. *Atmospheric Environment* **9,** 463–482.

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This article documents research that was conducted under the auspices of the U.S. Environmental Protection Agency (USEPA). As an arm of the government, the USEPA has a paid up, non-exclusive, irrevocable, worldwide license to reproduce, prepare derivative works, and distribute to the public all of the material contained herein, and to grant others acting on its behalf the right to do so. The USEPA grants to the National Technical Information Service, Department of Commerce, the right to act as its agent in the distribution of this material.